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ABSTRACT

This work investigates, first, whether the integration of color and shape information is affected by attending to the stimulus location, and second, whether attending to a stimulus location enhances the perceptual representation of the stimulus or merely affects decision processes. In three experiments, subjects were briefly presented with colored letters. On most trials, subjects were precued to the stimulus location (valid cue); on some trials a nonstimulus location was cued (invalid cue). Subjects were less likely to incorrectly combine colors and letter shapes following a valid cue. The attentional facilitation afforded by the cue was not limited to feature integration, but also affected the registration of features. However, when the amount of feature information was strictly controlled, attention still affected feature integration. The results indicate that orienting attention to the location of the cue affects the quality of the perceptual representation for features and their integration. (Author).

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Does Attention Affect Visual Feature Integration?

by

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Running head: Attention and Feature Integration

Abstract

This work investigates, first, whether the integration of color and shape information is affected by attending to the stimulus location, and second, whether attending to a stimulus location enhances the perceptual representation of the stimulus or merely affects decision processes. In three experiments, subjects were briefly presented with colored letters. On most trials, subjects were precued to the stimulus location (valid cue); on some trials a nonstimulus location was cued (invalid cue). Subjects were less likely to incorrectly combine colors and letter shapes following a valid cue. The attentional facilitation afforded by the cue was not limited to feature integration, but also affected the registration of features. However, when the amount of feature information was strictly controlled, attention still affected feature integration. The results indicate that orienting attention to the location of the cue affects the quality of the perceptual representation for features and their integration.

Does Attention Affect Visual Feature Integration?

The present study involves two areas of research in visual perception. The first concerns how the visual system combines information about independent stimulus features, such as color and shape. If different features or attributes of an image are processed independently, then these features must somehow be combined to yield a veridical view of the world. The second area concerns what it means to attend to a particular area in visual space. The specific questions that we will attempt to answer are, first, does attention affect visual feature integration, and if so how? Second, does attending to a particular object or location affect the quality of the perceptual representation?

Attention in Psychology has several different operational and theoretical definitions (Hirst, in press; Keele & Neill, 1978). In the experiments described in this paper, attention is defined operationally as the benefit in recognition or detection performance that occurs when subjects are cued in advance to the location of relevant stimulus event (Posner, Nissen, & Ogden, 1978). This facilitation has been called covert orienting by Posner (Posner, 1978) because it can occur independently of eye movements. Several investigators have demonstrated this type of facilitation (e.g. Bashinski & Bacharach, 1980; Jonides, 1980, 1981;

Posner, 1980; Posner, Snyder, & Davidson, 1980). An experiment reported by Jonides (1976) exemplifies this effect. On each trial, subjects were briefly presented an array of 4 letters and they had to decide as quickly as possible whether the display contained the letter L or the letter R. On VALID trials the stimulus display was preceded by a cue that indicated the position where the target would appear. On INVALID trials the cue indicated a nontarget position. Subjects were both faster and more accurate in target identification on valid trials than on invalid trials even when there was not enough time to complete an eye movement before the end of a trial. These results and others seem to correspond to the phenomenal impression that it is possible to fixate one's eyes on one location, and at the same time attend elsewhere (Helmholtz, 1925).

There are at least two ways of describing the benefits of a cue. The first type proposes that attention facilitates performance by improving the pick-up of information in the cued position (Jonides, 1983; Posner et al., 1978). Thus attention affects the quality of the perceptual representation. More information about the the presence of features, and perhaps about the combinations of these features, exists in the cued location than in the uncued locations. The second type of theory accounts for the facilitation in performance in terms of decision processes (Kinchla, 1980; Shaw, 1984). According to these decision

theories, the pick-up of information is not affected by the cue. To understand how the cue affects performance in a task such as the experiment by Jonides, described above, consider what could happen if there was no cue. On each trial, there is some probability that one of the non-target items will be incorrectly identified as a target item and this may lead to an error. The probability of incorrectly identifying a noise item as the target item increases as the number of noise items increase (Gardner, 1973). With a valid cue, subjects may be able to disregard the possibly misleading information from the noise items when they decide which target was present. A valid cue, in a sense, reduces the effective display-size from four items to one item. However, the quality of the representation in the cued and non-cued locations is assumed to be the same. The question of whether attention affects the form of the representation or merely a decisional process is a central interest of this study.

The second area addressed by this study concerns the integration or combination of features in vision. There exists considerable evidence that different stimulus attributes, such as color and shape, are at some level(s) of analysis processed separately (see Prinzmetal & Millis-Wright, 1984, for a review). If this is so, then part of the job of visual analysis is not just to correctly register features, but to correctly combine this information. In this study, we will be concerned with features of shape (i.e. letter

identity) and color, although feature integration is a logical problem in vision regardless of whether "features" are letters and colors, parts of letters, or even spatial frequencies (Wolford & Shum, 1980). If the visual system correctly registers features of color and shape, but does not correctly combine this information, then subjects should occasionally perceive colors and shapes in incorrect combinations. Treisman and Schmidt (1982) found in whole-report, partial-report, search, and same-different tasks that, with briefly presented colored letters, subjects reported colors and letters in incorrect combinations more often than expected by chance. For example, if subjects were presented with a red X, blue T, and brown N, they may have perceived and reported the X as blue. Treisman and Schmidt called this type of error a conjunction error or an illusory conjunction. Errors that resulted from not perceiving either the color or shape were referred to as feature errors.

Treisman has proposed that attention is the "glue" that correctly combines features (Treisman & Gelade, 1980; Treisman & Schmidt, 1982). However, the fact that the visual system must somehow combine feature or attribute information is logically distinct from the proposal that visual attention mediates this integration. There are theories of feature integration that do not necessarily involve attention (e.g. Prinzmetal, 1981; Wolford, 1975). Nevertheless, there are atleast two lines of evidence that suggest that attention

might be involved in feature integration. The first comes from a series of studies conducted by Treisman and her colleagues that examine search reaction time (RT) as a function of display-size (Treisman, 1982, Experiments 1,3; Treisman & Gelade, 1980, Experiments 1,4; Treisman & Paterson, 1984, Experiment 2; Treisman, Sykes, & Gelade, 1977, Experiment 1). In these experiments, subjects were asked to search for a target that was defined by single features (e.g. the letter X or any blue letter) or to search for a target that was defined by a conjunction of two features (e.g. a blue X).

In conjunction search, subjects presumably attend serially to each item in the display to avoid making a conjunction error. When searching for conjunctively defined targets, reaction time increased linearly with display size. In feature search, serial attention to each item is not necessary. There are unfortunately, several problems in interpreting reaction time data in this situation. First, it is very difficult to identify serial and parallel processes only on the basis of mean reaction times (Townsend, 1971; also see Egeth, Virzi, & Garbart, for a hybrid model). Second, in each experiment, reaction time did increase with feature search so that even feature search does not appear to be conducted with unlimited capacity (Treisman & Gelade, 1980, p. 118). Third, increases in reaction time with display size might be the result of decisional processes and not attentional limitations (see, for

example, Shaw, 1984). Finally, conjunction search might be limited by attention, but it might not operate in a strickly serial manner (e.g. Treisman, 1982). Although suggestive, the reaction time results do not unambiguously show that attention is involved in feature integration.

The second source of evidence for the role of attention in feature integration comes from a comparison of two partial report experiments by Treisman and Schmidt (1982; Experiments 4 & 5). In these experiments, subjects were presented 4 colored shapes and they were instructed to report all they could about the one item indicated by a bar marker. In one experiment, an attempt was made to prevent attention from being allocated to the target item (Experiment 4), while in the other experiment, attention to the target item was not prevented (Experiment 5). In Experiment 4, the partial report marker appeared after the stimulus, subjects had a dual task, and the exposure durations were relatively long (averaged 199 msec). In Experiment 5, the bar marker appeared before the stimulus, there was no dual task, and exposure durations were relatively short (averaged 89 msec). The estimated number of conjunction errors was much greater in the first experiment. Ofcourse, in comparing two experiments that differed in a number of ways, it is difficult to attribute the outcome to any particular cause. Furthermore, as we will discuss in more detail later, there are special measurement problems in comparing conjunction errors across different conditions.

Nevertheless, given the various results of Treisman and her colleagues, it seems likely that attention is in some manner involved in feature integration.

Experiment 1

Our study sought to examine the role of attention on feature integration by precuing the target location. We wished to determine whether spatial attention affects conjunction errors alone, or whether it also affects feature errors. Furthermore, we wanted a procedure where valid cues did not indicate which item was the target, but rather it would indicate where all of the stimuli were located. Hence, any effect of cuing would not be the result of differentially weighting information from the target item in a decision stage, but it would reflect a difference in the quality of perceptual representation. If cue validity has an affect, then it would indicate that more information about features or about their correct integration is availiable in the attended location. The paradigm for our first two experiments is illustrated in Figure 1.

Insert Figure 1 about here

On each trial, subjects were first shown a colored target letter, such as a pink X. This was replaced by first a fixation point and then a pair of arrows that pointed to one

of four locations on the field. The arrow cues were followed by the stimulus which contained 4 colored letters. Finally, the stimulus was replaced by a mask. The subject was to respond whether the colored target appeared in the field. For example, if the target was a pink X, they were to give a positive response if and only if they saw a pink X. On valid trials, the cue indicated the quadrant that contained the target and noise items (see Figure 1). On invalid trials, the cue indicated a location that did not contain the target and noise items.

Feature errors and conjunction errors were measured by examining the false alarm rates with two kind of stimuli (see Treisman & Schmidt, 1982, Experiment 2). A feature stimulus matched the target in either color or shape, but not both. For example, if the target were a pink X, the stimulus might contain a blue X and no pink letters, or pink letters but no X. False alarms with these stimuli are a measure of only feature errors. A conjunction stimulus contained the target letter and color, but in incorrect combination. For example, if the target were a pink X, the stimulus might contain of a pink O and a blue X. A false alarm to this stimulus may indicate a conjunction error since a subject could have combined the pink of the O with the X. However, a false alarm with a conjunction stimulus might also indicate a feature errors. For example, subjects might make a false alarm if they do not accurately perceive the color. In summary, false

alarms to feature stimuli measure feature errors, while false alarms to conjunction stimuli may indicate both feature and conjunction errors.

Method

Procedure. The sequence of visual events during a trial is outlined in Figure 1. At the beginning of a trial a letter X appeared in the center of the monitor. The color of this letter was chosen from the set {pink, yellow, green, blue} and remained the same for all trials within a block. After 1 sec the target was replaced by a small fixation point. Subjects were instructed to keep their eyes fixed on this point for the remainder of the trial. After the fixation point had been displayed for 500 msec, two white arrows (the cue) appeared in one of four locations near the four corners of the monitor screen. Subjects were told that the arrows correctly indicated, on most of the trials, the location where the subsequent stimulus would appear. After the cue had been displayed for 127 msec, the stimulus appeared either in the gap between the two arrows (valid trial) or in the corresponding location in one of the other three corners of the monitor (invalid trial). The stimulus was displayed for 100 msec and consisted of 4 colored letters (3 Os and one X, or 4 Os).[1] The fixation point and the cue remained present during the display of the stimulus. Following the stimulus presentation, the stimulus and the three other corner locations on the screen where stimuli could occur, were masked

with solid white rectangles. The location of the stimulus was chosen randomly and, on invalid trials, the location of the cue was chosen at random from among the three possible nonstimulus locations. Two-thirds of the trials in a block were validly-cued and one-third were invalidly-cued. The order of presentation of stimuli within a block was random.

Following three 20-trial blocks for practice, subjects were given eight blocks of 72 trials each. There were two blocks for each of the 4 possible target colors (presented in random order). On one-third of the trials (i.e., one-third of the valid trials and one-third of the invalid trials), the target letter-color combination was present in the stimulus (target-present stimulus). On one-third of the trials, the target letter (X) and the target color were present, but not in combination (conjunction stimulus). That is, the target color belonged to two of the Os, and the remaining O and the X were of another (nontarget) color. On one-sixth of the trials the target letter (X) was present and the target color was not present (letter-present stimulus). Finally, on one-sixth of the trials, the target color was present and the target letter was not present (color-present stimulus). In the color-present stimuli, all of the items were the letter O. These various trial-types were randomly interspersed within a block.

We wished to minimize the number of misses (response of "no" on target-present trials) since it is not possible to

determine whether a miss is due to a conjunction error or to a feature error. Thus subjects were informed when they made miss errors by the occurrence of a brief tone from the computer. Subjects were not informed when they made errors other than misses.

Stimuli. The stimuli were presented on a Heath-Zenith 13-inch color monitor (model 13-PF-5) controlled by an Apple 2e computer. Ambient lighting was from fluorescent ceiling lights. Subjects viewed the display from a distance of 210 cm. The fixation point subtended a visual angle of 0.05 deg. The length of each arrow and the width of each arrowhead subtended 0.41 and 0.46 deg of visual angle, respectively. The arrows were oriented horizontally with the two heads pointing toward each other. The tips of the two arrowheads were separated by a gap subtending 0.95 deg of visual angle. The visual angle separating the center of the arrow pair from the center of the monitor screen (fixation point) was 1.25 deg. The stimulus consisted of a rectangular cluster of four letters: either one X and three Os, or four Os. Two colors were present in any given stimulus cluster: two letters of one color and two letters of another color. The colors, the positions of the two colors within the letter cluster, and the location of the X within the letter cluster were randomly determined. The colors matched Munsell values 5RP 7/10 (pink), 10YR 8/14 (yellow), 2.5BG 8/6 (green), and 5PB 6/10 (blue). An individual letter subtended 0.31 deg of

visual angle in height and 0.27 deg in width. The distance between letters was equal to the width of a character stroke (approx. .03 deg). Each white rectangle in the mask subtended 0.71 by 0.79 deg.

Subjects. Sixteen subjects, recruited from the subject pool at the University of Oregon, were paid for their participation in the one-hour session. They ranged in age from 16 to 38 years; eleven were female and five were male. All had normal or corrected-to-normal acuity and no known deficiencies in color vision.

Results

The critical results in this experiment, the false alarms with the target absent stimuli, are shown in Figure 2. Subjects made significantly more false alarms when the stimulus contained the target color and letter (conjunction stimuli), than when the stimulus contained either the target letter or the target color but not both (feature stimuli), $F(1,15) = 59.35$, $p<.01$. The mean false alarm rates for conjunction and feature stimuli were .32 and .05, respectively. Subjects were also more likely to make a false alarm on invalid trials than on valid trials, .22 vs. .15, $F(1,15) = 12.52$. The interaction of cue validity and feature vs. conjunction stimulus was significant, $F(1,15) = 8.61$, $p<.05$. When considered separately, the cue validity effect was significant for both the conjunction stimuli and feature stimuli, $t(15) = 3.52$ and 2.44, $p< .05$,

respectively. Considering only the two types of feature trials, there was a cue validity effect for false alarms when the target color was present, .057 vs. .113, $t(15) = 2.54$, $p < .025$. When the target letter was present, the validity effect was in the same direction, but not significant, .014 vs. .022, $t(15) = 1.07$. The failure to obtain a validity effect with the letter-present feature trials is probably due to a ceiling on performance. Finally, there was no significant difference in the miss rates for valid and invalid trials, .15 vs. .19, $t(15) = 1.34$.

Insert Figure 2 about here.

Discussion

Although the results on this experiment were very simple, the interpretation is more complex. The difference between valid and invalid cues was greater than for the conjunction stimuli than the feature stimuli. One might be tempted to assert from this data that cue validity is more important for feature integration than feature extraction. This would be an unwarranted conclusion. Notice that we do not know the exact number of conjunction and feature errors but we have only indirect measure of them with false alarm rates. The function that relates false alarms to feature and conjunction errors is unknown and many reasonable monotonic

transformations of the number of feature and conjunction errors could give us a spurious interaction in the false alarm rates (Loftus, 1978). If it is inappropriate to claim that the cue is more important to the process of feature integration than feature extraction, perhaps it can be concluded that attention effects both. The problem here is although false alarms with feature trials are a measure of only feature errors, false alarms with conjunction stimuli represent an unknown mix of feature and conjunction errors. The only defensible conclusion that can be made from this experiment is that attention affects feature errors. This conclusion is justified because false alarms with feature stimuli can only arise from feature errors. However, we can not claim that all the conjunction false alarms arise from conjunction errors.

Given that cue validity affects feature errors, and the analytical constraints discussed above, the problem is how to test whether attention affects feature integration in a manner that is independent of feature extraction. One possibility is that if the proportion of feature errors could be equated on valid and invalid trials, then a direct comparison of conjunction errors would be possible. This is what we attempted to do in Experiments 2 and 3. It is important to note that we are not claiming that attention does not affect feature registration. Experiment 1 clearly shows that feature extraction benefits from attention. The question

is, if we could equate the amount of feature information in valid and invalid trials, will attention affect the proportion of conjunction errors?

Experiment 2

In Experiment 2, an attempt was made to equate valid and invalid feature errors by reducing the amount of feature information available on valid trials. This experiment was, but for two modifications, exactly like Experiment 1. The first and the most important difference was that the exposure duration of the valid trials was adjusted following each block so that the proportion of feature errors was approximantely the same for valid and invalid trials. The exposure duration for valid trials was initially set at 100 msec If a subject made more feature false alarms on invalid than on valid trials, the exposure duration on all valid trials was reduced on the next block of trials by one refresh cycle of the monitor (16.67 msec). Therefore the exposure duration of the valid trials was always equal to or less than the exposure duration of the invalid trials. The exposure duration for valid trials ranged from 50 to 100 msec and averaged 85.25 msec. The exposure duration of the invalid trials was always 100 msec. The idea was to reduce the amount of feature information in the valid trials to the amount in invalid trials.

The second modification was to reduce the time that the cue was presented to 100 msec, so that the total time from

the onset of the cue to the offset of the stimulus was 200 msec. We did this to further guard against eye movements. Sixteen subjects (7 female) were recruited as before. Four of the subjects had participated in Experiment 1.

Results

The false alarms rates for this experiment are shown in Figure 3. As in Experiment 1, subjects made significantly more false alarms with conjunction stimuli than with feature stimuli, .43 vs. .12, $F(1,15) = 58.86$, $p<.01$. The interaction of the type of stimulus with cue validity was significant, $F(1,15) = 18.08$, $p<.01$. As in the first experiment, the cue had a significant effect in reducing false alarms with conjunction stimuli, .241 vs. .309, $t(15) = 3.47$, $p<.01$. Unlike the previous experiment, cue validity had no effect with the feature stimuli. Overall, the false alarm rate for valid and invalid feature stimuli was .115 vs .124, respectively, $t(15) = .48$ (S.E. of difference = .01824). Of the 16 subjects, only 7 had fewer false alarms with valid cues than with invalid cues. When the feature trials are further broken down into those with the target color-present and those with the target letter present, neither show an effect of cue validity. For color present feature stimuli, the false alarm rates were .185 vs. .207, $t(15) = .635$, for valid and invalid cues, respectively. For the letter-present feature stimuli, the false alarm rates were .045 vs. .041, $t(15) = .38$, respectively. Finally, the miss

rates for valid and invalid cues did not significantly differ, .258 vs. .247, $t(15) = .35$.

Insert Figure 3 about here.

Discussion

From the results of this experiment, it can be concluded that attention can affect feature integration, independent of the effect of attention on feature extraction. We are not claiming that attention does not affect the proportion of feature errors, but rather attention has an effect on feature integration that can not be explained by the effect of attention on feature errors. Formally, the only assumptions that need be made in this experiment are that feature errors are monotonically related to the number of feature false alarms and that conjunction errors are monotonically related to the number of conjunction false alarms. Since false alarms on feature trials only represent feature errors, and these do not vary with the type of cue, the true proportion of feature errors was the same with valid and invalid cues. Hence, the difference in false alarm rates with valid and invalid conjunction stimuli can only represent a difference in conjunction errors.

A comment on the method of equating feature errors is in order. We are not implying that manipulating exposure duration uniquely affects feature errors and not conjunction

errors. With unlimited exposure to our stimuli, subjects would make neither feature errors, nor conjunction errors. As exposure duration is decreased, subjects would begin to make both feature errors and conjunction errors. These two types of errors may grow at different rates as exposure duration is decreased. Our manipulation of exposure duration for valid trials was successful because it was in a range where a change in duration happened to affect feature errors more than conjunction errors. The logic of our conclusions rests on the empirical equating of feature errors and not on any a prori assumptions about feature integration and exposure duration.[2] In the final experiment, we attempted to equate feature errors on valid and invalid trials with a method that did not require a physical difference in valid and invalid trials.

Experiment 3

The final experiment had two goals. First, we wanted to equate feature errors without using different display parameters for valid and invalid trials. Second, our results would have greater generality if we measured conjunction and feature errors in a different manner. In this experiment, the stimulus displays were similar to the previous experiments, except that each of the stimuli contained either the letter X or the letter F. The subjects' task was to respond whether the stimulus contained an X or an F and to report the target's color. For example, a typical response would be "pink X". Letter feature errors were measured with the proportion of

trials in which the subjects responded with an incorrect letter. Color feature errors were measured with the proportion of trials in which subjects responded with a color that was not part of stimulus array. Conjunction errors were measured with the proportion of trials in which subjects responded with the correct letter, but combined with a color of a nontarget item.

We tried to equate feature errors on valid and invalid trials by attempting to have subjects make no feature errors. One might object that this creates a ceiling effect and that might disguise an effect on feature errors. We are not claiming that attention does not affect feature errors. The question is if feature errors are equated across attention conditions, will the cue affect feature integration? To reduce the proportion of feature errors, the task was made easier by using slightly more saturated colors and placing the letters in the stimulus clumps a little further apart.

Method

Procedure. The beginning of a trial was signalled by a tone from the computer. Following the tone, a small fixation cross (subtending 0.14 deg of visual angle) appeared in the center of the television screen. After the fixation cross was displayed for 1 sec, the cue (two horizontal white arrows pointing toward each other) appeared in a direction toward one of the four corners of the television screen. The cue was displayed for 100 msec prior to the appearance of the

stimulus. The stimulus contained three Os and either an X or an F. The stimulus colors and arrangements were chosen as in the previous experiments. Eighty percent of the trials in a block were validly-cued and 20% were invalidly-cued. The two types of trials were randomly interspersed. The subjects' task was to verbally report whether the display contained an X or an F and to report the target's color. For example, typical responses would be "pink X" or "blue F". Responses were recorded by the experimenter. Following three 20-trial blocks for practice, subjects were given five 100-trial blocks.

Stimuli. Subjects viewed a 13-inch Zenith color television monitor from a distance of 210 cm. The colors, which were chosen to be more discriminable than in the first two experiments, matched the following Munsell values: "pink" (3.75RP 6/12), "yellow" (2.5YR 7/10), "green" (10GY 8/8), "blue" (10B 6/10). In the first two experiments, the letters seemed difficult to discriminate because they were crowded together (the inter-item distance was about .03 deg visual angle). In this experiment, the inter-item distances were increased to about .20 deg. Thus the rectangular cluster of items was slightly larger subtending a visual angle of 1 deg by .78 deg. Corresponding to this slightly larger stimulus display, the tips of the two arrowheads were separated by a gap subtending 1.19 deg visual angle and each of the masking rectangles subtended 1.09 by 1.01 deg of visual angle. The

visual angle separating the center of the 4 stimulus items and the fixation point was 1.36 deg. Otherwise, the spatial layout of the cues, the stimuli, and the masks, was as in the previous experiments. Sixteen subjects (10 female) were recruited as before to participate in a one-hour session. Five of the subjects had participated in experiments 1 or 2.

Results and Discussion

The results of this experiment were quite remarkable. Subjects erred in identifying the target letter (X or F) on less than 2% of the trials. Furthermore, subjects reported a color that was not present in the stimulus array on less than 1% of the trials. Although this is not perfect performance, it is fair to say that the subjects had little trouble seeing the target letters and the stimulus colors. Nevertheless, subjects reported the target in a color of one of the noise items on 14.7% of the trials. An intuitive definition of conjunction errors involves situations where subjects clearly perceive the colors and letters in the display, but incorrectly combine this information. The present results, to us, satisfy this intuitive definition. The data is broken down by category in Table 1.

Insert Table 1 about here.

Conjunction errors were measured with the proportion of trials in which subjects reported the correct target

letter, but combined with the nontarget color present in the stimulus. Subjects made significantly more of these errors on invalid trials than on valid trials, .174 vs. .119, $t(15) = 4.26$, $p<.01$.

There are a variety of errors that measure feature errors (see Table 1 - B to E). For example, subjects could err in reporting the target color. Alternately, they could report the letter correctly, but report a color that was not part of the stimulus display (OFF error). None of these error types by themselves exceeded 1% and so analysis in probably inappropriate. When all of these measures of feature errors are summed, the difference between valid and invalid trials was not significant, .0207 vs. .0263, $t(15) = 1.43$. Of the sixteen subjects, only 9 had fewer total feature errors on valid than invalid trials. For each of the error types B to E, taken individually, never more than half of the subjects had fewer errors on valid than invalid trials.

The purpose of this experiment was to equate feature errors in valid and invalid trials by creating a situation where subjects would make virtually no feature errors. This, of course, does not show that attention only affects feature integration, but rather a difference in feature errors cannot explain the effect of attention on conjunction errors. To underscore this point, we divided our subjects into those that did and did not have fewer total feature errors with valid than invalid trials. The seven subjects who did not have

fewer feature errors with valid cues nevertheless showed a significant effect of cue validity on the measure of conjunction errors, $t(6) = 2.50$, $p < .05$.

General Discussion

Experiment 1 demonstrated that attention affects feature extraction. Attention also was shown to affect feature integration in a manner that cannot be accounted for by an artifact of measuring conjunction errors. Feature errors were held constant using two different methods and cue validity still affected feature integration (Experiments 2 & 3). To use a metaphor, it seems that the spotlight of attention both illuminates and helps integrate features. In light of the present results, three issues should be addressed. First, this research bears on the nature of the facilitation that occurs when subjects are cued to attend to a particular item or location. Second, several different perspectives on theories of feature integration need to be reexamined in light of the present results. Finally, this research has clear methodological implications for a number of questions that might be asked about feature integration.

The present study addresses a fundamental issue in the nature of attention. Recall that one set of theories postulates that attention affects the quality of the internal representation of the stimulus. Other theories postulate that the effect of the cue is not on the quality of the representation, but on the weight assigned to each stimulus

item. More weight is assigned to the cued item than to noncued items. These studies provide prima facie evidence that the quality of the representation is affected by the cue. In the present experiments, the cue indicates where the four stimulus letters will appear, but it does not indicate which of the stimulus items is the target. Hence the cue does not allow a subject to ignore the noise items in making a decision.

There is a particularly virulent form of the decision theory that is more difficult to deal with. The idea is that all tasks can be considered a search task. Consider an experiment by Posner and his colleagues that measured simple RT to the onset of one of two lights in an empty field (Posner et al., 1978). Simple RT was found to be faster when the light was preceded by a valid rather than an invalid cue. In this case, there does not seem to be competing noise item information to affect response selection. However, Duncan (1984b) has argued that the nontarget location could be considered as a kind of phantom noise item and the subject must discriminate that item from an actual light (signal). A valid cue would decrease the probability that the phantom noise item would be considered a signal. In the present experiments, one might consider the task as discriminating the target item from three real noise items and 12 other phantom items located in the other 3 quadrants. A valid cue would in effect reduce the display-size from 16 to the actual four

items. This explanation can be easily rejected on the basis of the present results. Consider the last experiment and what would happen if the non-stimulus locations did contain randomly generated phantom noise items. These phantom items would increase the number of feature errors because they would induce subjects to respond randomly with colors and letters that were not necessarily part of the stimulus. A valid cue would reduce these phantom feature errors. However, in the last experiment, subjects were very unlikely to report colors and letters that were not present. More importantly, in both Experiments 2 and 3, the cue did not effect any of our measures of feature errors. The only effect of the cue was on the measure of conjunction errors, and this is not predicted by the phantom feature theory. Thus, we have evidence that the internal representation for items in the attended location contains more information about the combination of features than for items in the unattended location.

Several times we have used the metaphor of a spotlight for attention. This metaphor accurately describes a number of attentional phenomenon. For example, like a spotlight, attention may take time to focus down to a single item (Eriksen & Hoffman, 1972; Eriksen & Rohrbaugh, 1970) and there may be a minimum effective size of the field of attention (Eriksen & Hoffman, 1973). Attention may take time to move from place to place (Tsal, 1983). Finally, attention may move in an analog fashion across the field (Shulman, Remington, &

McLean, 1979). On the other hand, there are a number of ways in which attention is not like a spotlight (e.g. Duncan, 1984a). Furthermore, the analogy does not specify a number of properties of spatial attention such as the effect of task difficulty on the time it takes to disengage attention (LaBerge, 1973). Finally, an attentional spotlight must be controlled by something, and this control would also be part of an attentional system. Although the spotlight metaphor is a handy way to refer to some of the properties of visual attention, it is not necessary to describe the present results. Our results simply show that more information is available in cued locations than in uncued locations. These results, by themselves, are neutral with respect to other properties of attention.

The present findings establish constraints on theories of feature integration. However, at least three present theories can handle our results. Of these accounts, Treisman's theory is the only one that makes explicit use of attention (Treisman & Gelade, 1980). According to this theory, features within the spotlight of attention are prevented from combining with features from outside the spotlight. Conjunction errors will be prevented if the spotlight focuses on a single item. This theory needs an additional assumption to explain the our results. This is because the positional cues in our experiments do not indicate which single stimulus item should be focused on. All of the

items initially would be in the spotlight on valid trials, and all of the items would be outside the spotlight on invalid trials. Hence, conjunction errors would not be prevented in either the valid or invalid trials. An additional assumption that could be used is that refocusing attention takes time in proportion to the distance that attention must travel. On valid trials, the spotlight needs only to narrow its focus to a single item, whereas on invalid trials, it needs to move across the field before focusing on a single item. The probability of completing the focusing to a single item would be greater on valid trials than invalid trials.

Wolford's feature perturbation theory makes no explicit reference to attention, and yet with a simple additional assumption, it may be able to explain the present results. According to Wolford (1975), features are extracted with location information. The spaces between letters are extracted like any other feature and serve to segregate feature bundles. With time, features perturbate to neighboring positions leading to recognition errors. To explain the present results, one needs only to assume that in the initial feature extraction stage, the probability of picking up information about spaces is greater in the attended location than in the unattended location. Hence there would be more information about the correct combination of features following a valid cue than an invalid cue.

Prinzmetal's perceptual grouping hypothesis could

account for the results by also appealing to the idea that more information in available in the attended location. Prinzmetal (1981; Prinzmetal & Millis-Wright, 1984) proposed that the visual system parses stimuli by rules analogous to the Gestalt principles. The parsing can be hierarchical so that individual letters are units within larger units consisting of several letters. Features from different perceptual units are prevented from combining. To explain the present findings, one need assume that more detailed information about the organization of the stimulus display is available from attended locations. This would include information about the spaces between letters, but it would not be limited to that information. Attention could also affect performance by its affect on perceptual organization, but it is not necessary to appeal to this mechanism in the present study.

The present study makes explicit a methodological constraint in studying feature integration. Specifically, the problem is measuring conjunction errors in a manner that is independent of feature errors. Tests of a number of very interesting hypothesis hinge on a solution to this problem. Consider Wolford's hypothesis that features from the periphery are more likely to perturbate than features from items located in the center of the visual field (Wolford, 1975; Wolford & Shum, 1980). It is undoubtably true that it is more difficult to register features in the periphery. Hence a test of this

hypothesis depends on equating the amount of feature information either empirically (as was done in the present experiment) or theoretically. A theoretical solution would separate feature errors from conjunction errors in a manner analogous to the way signal detection theory separates signal detectability from the observer's criterion.[3] As a second example of this problem, consider an experiment by Duncan that tested Treisman's attention hypothesis (Duncan, 1979, Experiment 1). Subjects had to determine, as quickly as possible, whether an 8 item display contained the letter Q. Four of the item locations were designated as relevant and 4 were designated as irrelevant. The target (Q) could only appear in only one of the relevant locations. Reaction time was slower when features of the noise items could be combined to form a target (i.e. O and K), but only when these noise letters occurred in relevant locations. These results were taken as supporting the hypothesis that features from attented and unattended locations will not combine. However, an alternative account is that there was not much information about the troublesome features when they were in to-be-ignored locations.

Finally, it is important to note that attention can be operationalized in various ways and other attentional manipulations may or may not affect feature registration or integration. For instance, it would be interesting to know whether the attentional effects operative in visual feature

integration derive from a general cognitive resource or from processes specific to the visual system. If attention is a general cognitive resource, then perhaps any secondary cognitive task, such as a short-term memory task, might affect feature integration. On the other hand, only a visual dual task, such as reporting digits, may affect conjunction errors. Finally, it could be that only spatial attention, as defined in this paper, affects feature integration, but that a visual dual task will not. These are speculations for further research, the outcome of which has implications for both the problems of feature registration and integration in vision and also for the nature of attention.

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Footnotes

1. As the total presentation time for cue and stimulus (227 msec in Experiment 1; 200 msec in Experiments 2 & 3) was less than the time required to complete a saccade, eye movements were not monitored in our experiments. Subjects reported that they had no trouble maintaining eye-fixation. Moreover, on practice trials in which they attempted to move their eyes to the cue or the stimulus, subjects found that they did not see the stimulus as clearly, and were thus further motivated to hold their eyes fixed on the center of the monitor screen throughout a trial.

2. By the logic of this argument, if we had selected a different range of exposure durations and performance levels, it is possible that we could have obtained a difference in feature false alarms on valid trials (shorter exposure durations) and invalid trials (longer exposure durations), but not a difference in conjunction false alarms. The fact that it may be possible to obtain this result does not invalidate the logic of the present experiment.

3. It is probably inappropriate to use signal detection theory in the present situation. Shaw (1982) has shown in many instances where there are multiple sources of information in a search task, signal detection is not appropriate because subjects often make independent decisions on the basis of each source of information and then pool their decisions. In any experiment where the display size is

greater than one, this may be the case. The present two search experiments present an even more complex situation (Experiments 1 & 2). In order to make a presence/absence decision, subjects must combine information not only over different spatial positions, but also over dimensions of color and shape.

Figure Captions

Figure 1. An example of a valid trial.

Figure 2. Proportion conjunction and feature false alarms in Experiment 1.

Figure 3. Proportion conjunction and feature false alarms in Experiment 2.

Table 1

Error Proportions - Experiment 3

Type of Error	Valid	Invalid
A. Conjunction Letter Correct Color On	.119	.174
B. Color Error Letter Correct Color Off	.0034	.0094
C. Letter Error Letter Wrong Color Correct	.0084	.0094
D. Letter Error Letter Wrong Color On	.0084	.0069
E. Letter & Color Error Letter Wrong Color Off	.0005	.0006
All Feature Errors B+C+D+E	.0207	.0263

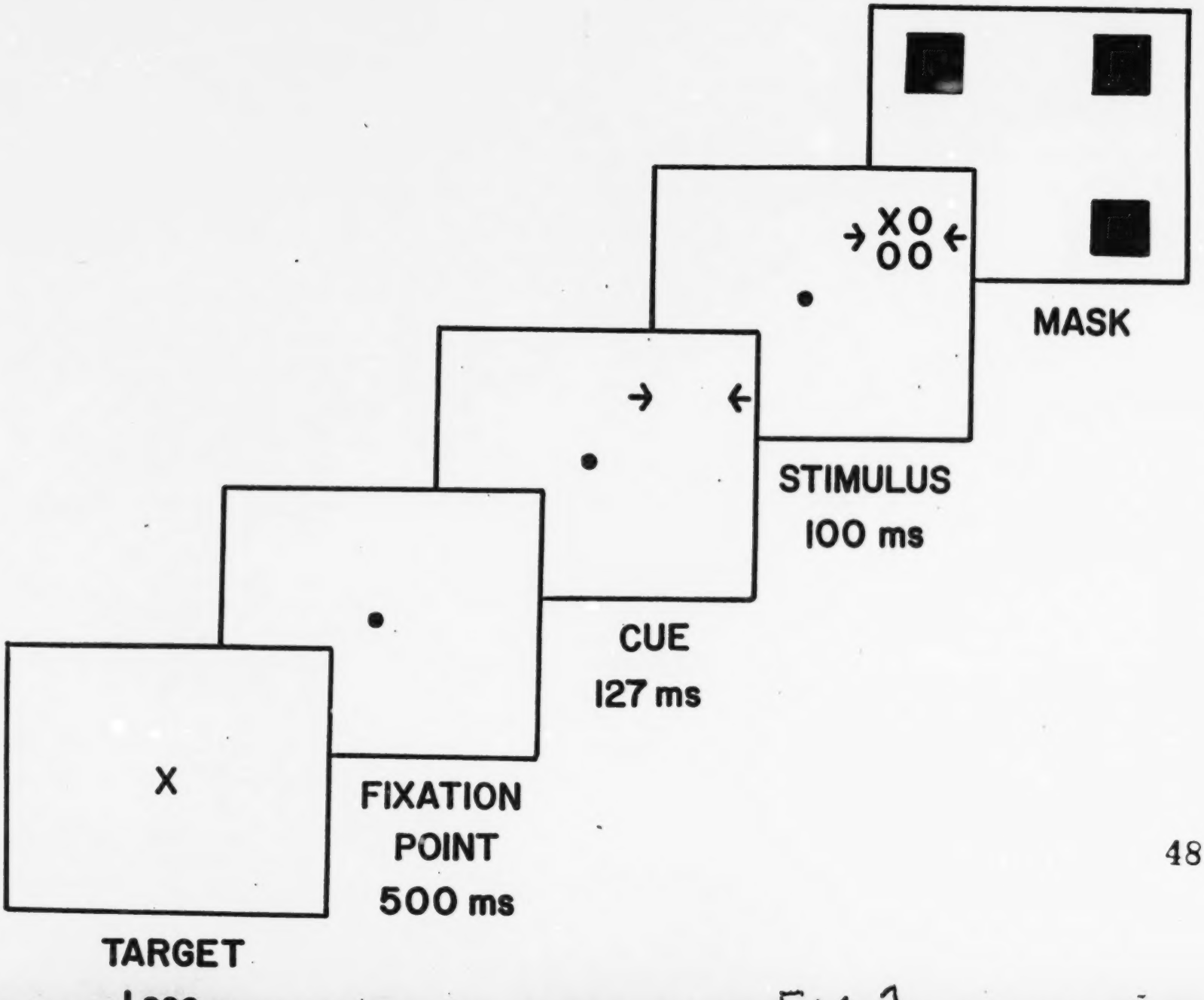
X
TARGET
1 sec
FIXATION
POINT
500 ms
CUE
127 ms
STIMULUS
100 ms
MASK

FIG. 1

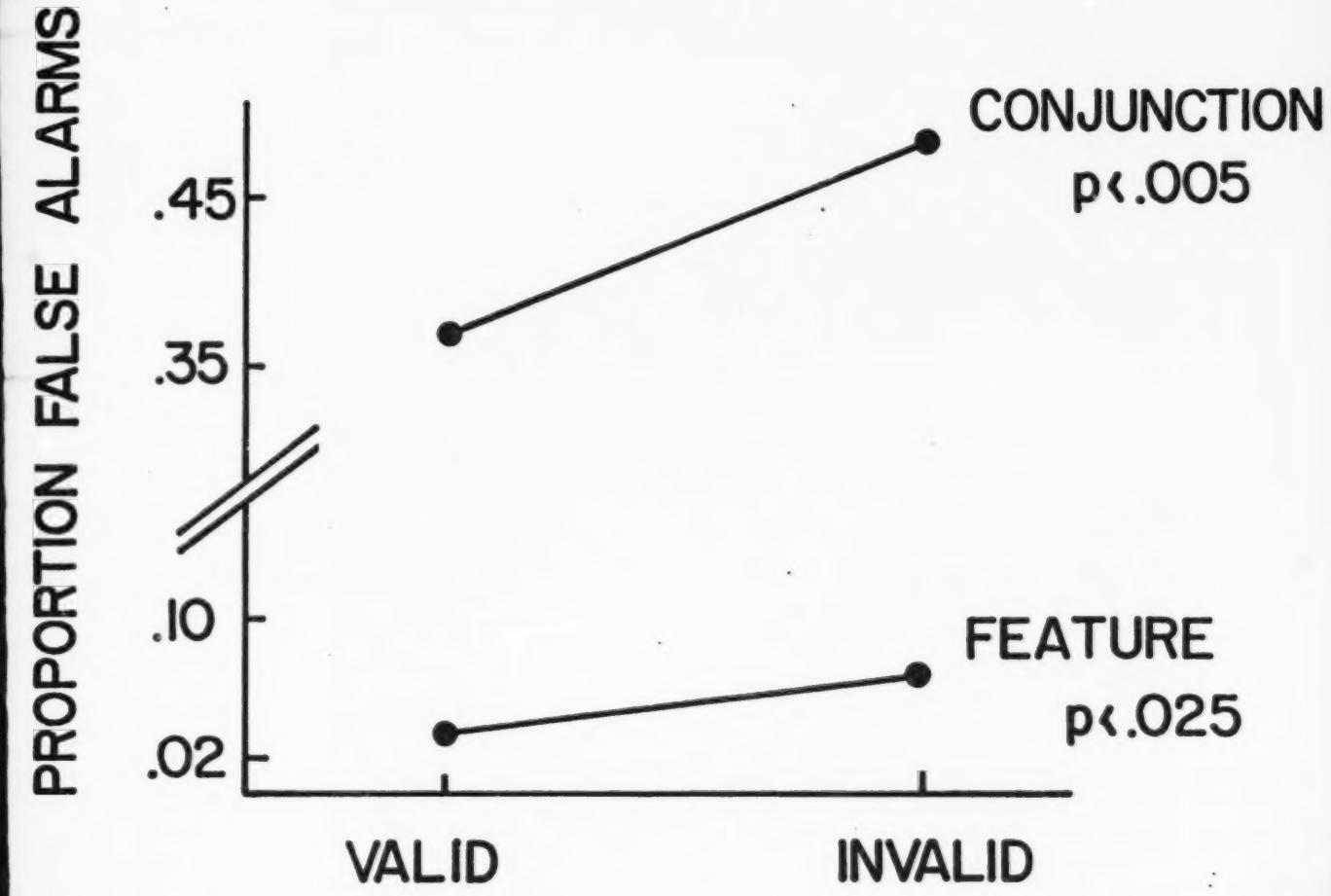
PROPORTION FALSE ALARMS
.45
.35
.10
.02
CONJUNCTION
p<.005
FEATURE
p<.025
VALID
INVALID

FIG 2

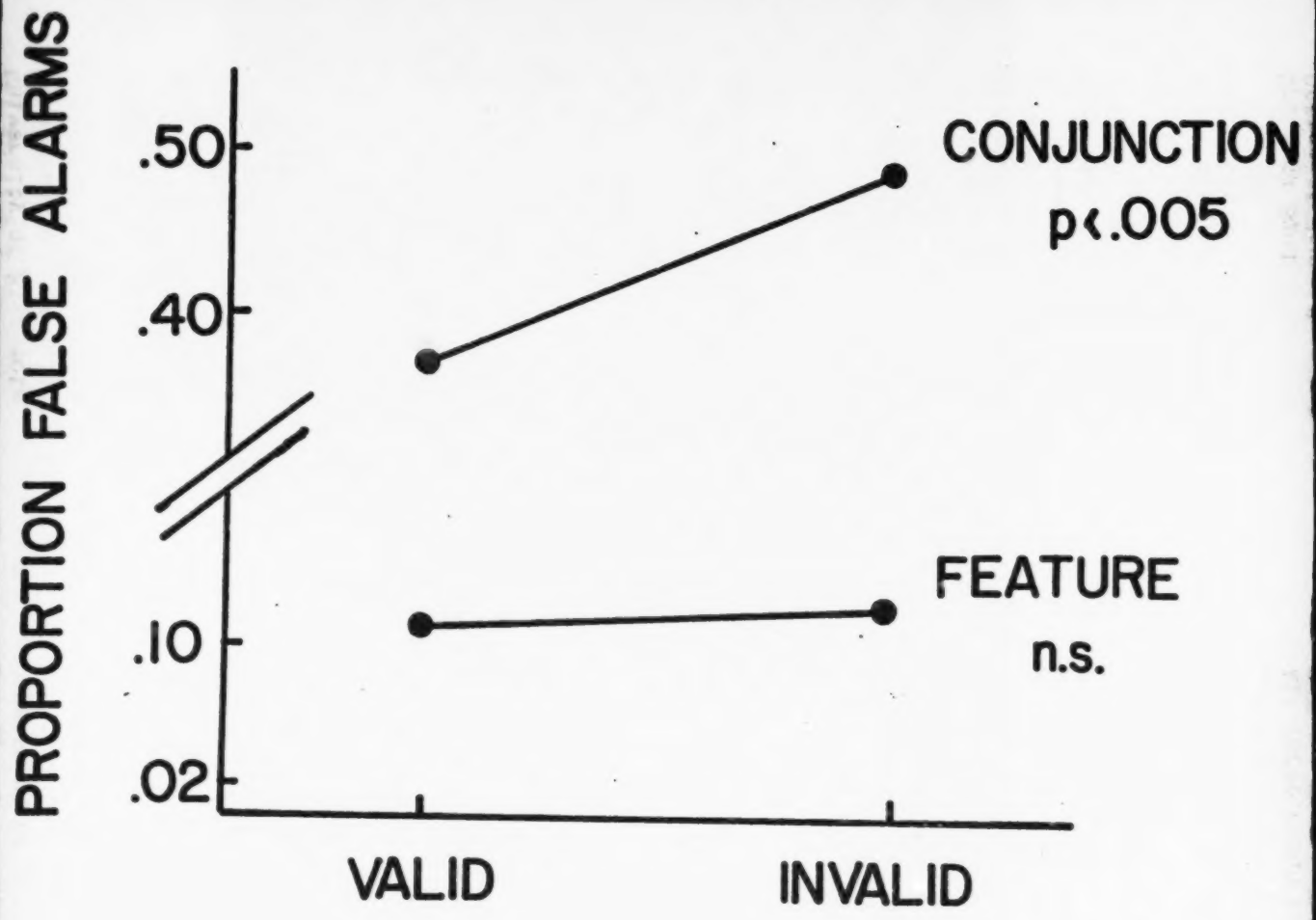
PROPORTION FALSE ALARMS
.50
.40
.10
.02
CONJUNCTION
p<.005
FEATURE
n.s.
VALID
INVALID

FIG 3

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